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(56) Documents Cited
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GB 2030056 A
EP 0055981 A1

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UK CL (Edition S) B1X
INT CL^7 B01D 61/06
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(54) Abstract Title
Energy recovery during desalination of seawater

(57) High pressure concentrated retentate is returned to a buffer tank 10 in order to force sea water into the reverse osmosis unit. The concentrate and seawater are separated, preferably by flexible impermeable barrier 7. The retentate is expelled from the tank as it fills with sea water. Preferably the extra force required to remove the seawater is supplied by a metal weight 9. The concentrate is removed from the separation unit by a siphon. The syphon feeds the retentate into the top of the buffer tank 10.

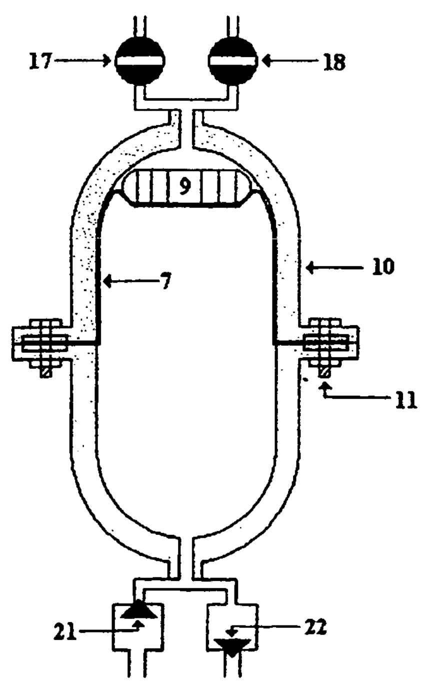

Figure 3b

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The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

Figure 1

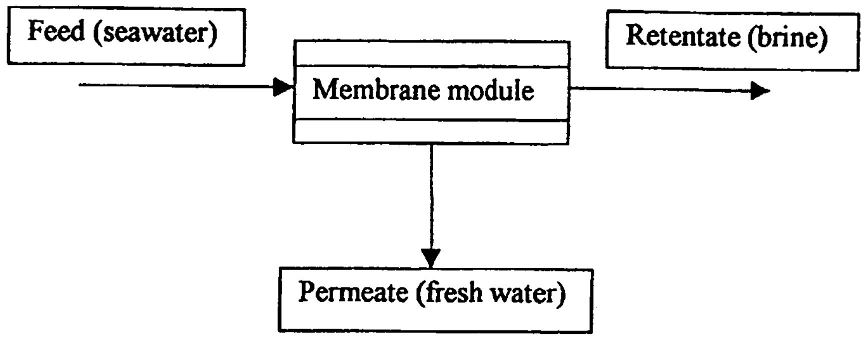


Figure 2

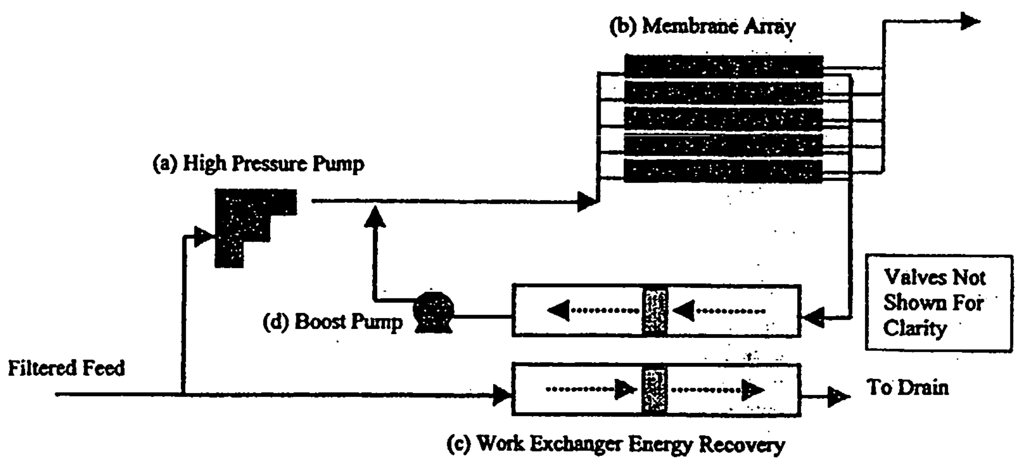


Figure 3

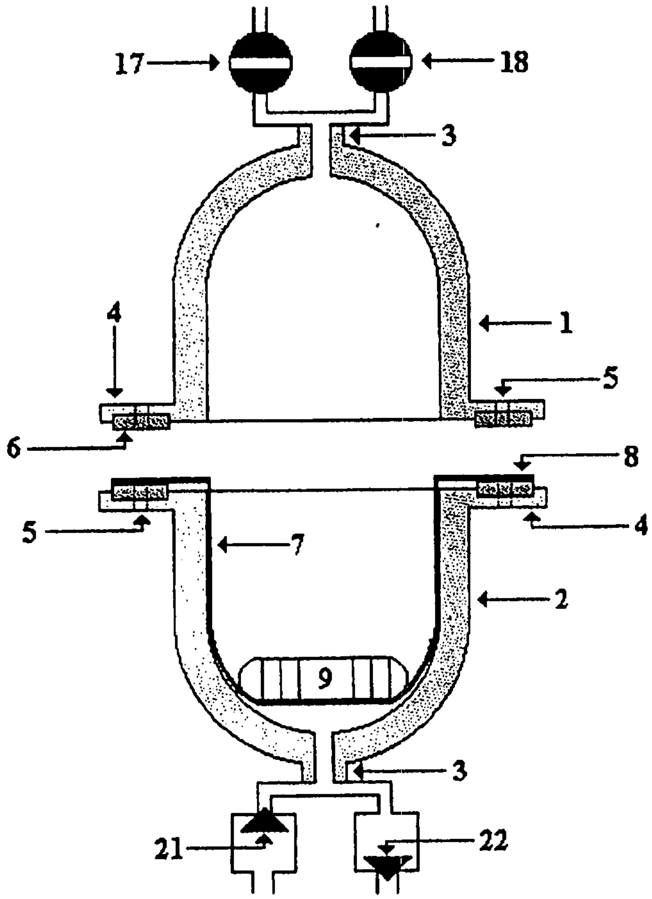


Figure 3a

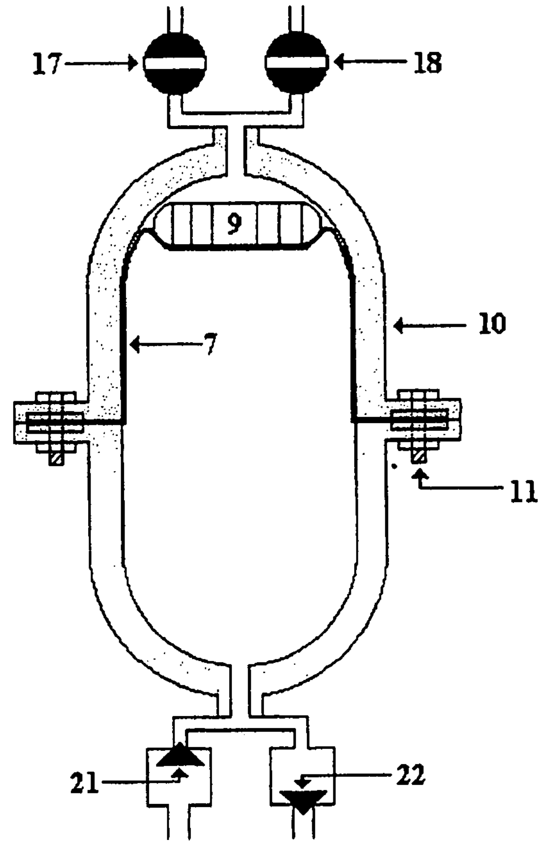


Figure 3b

Figure 4

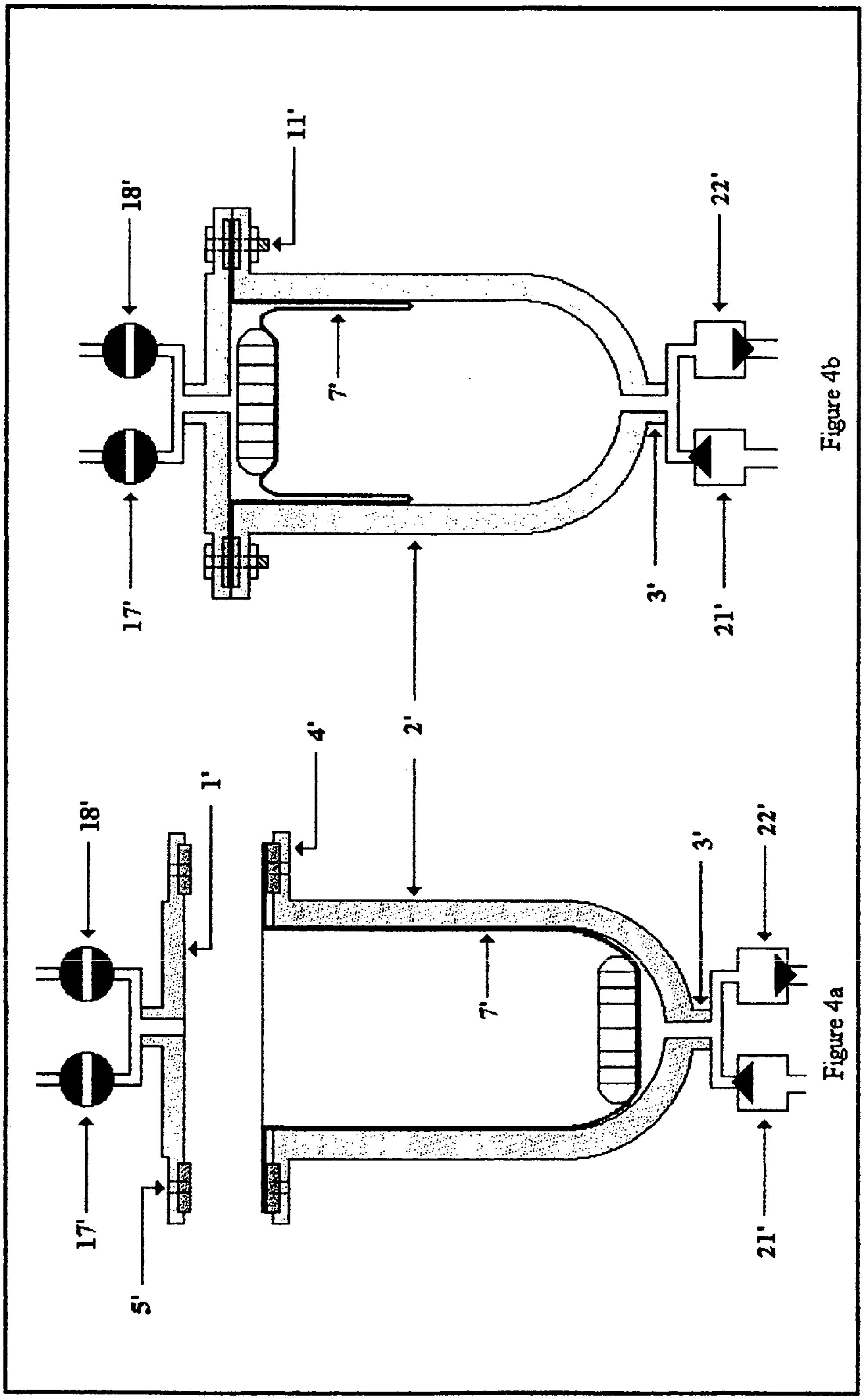
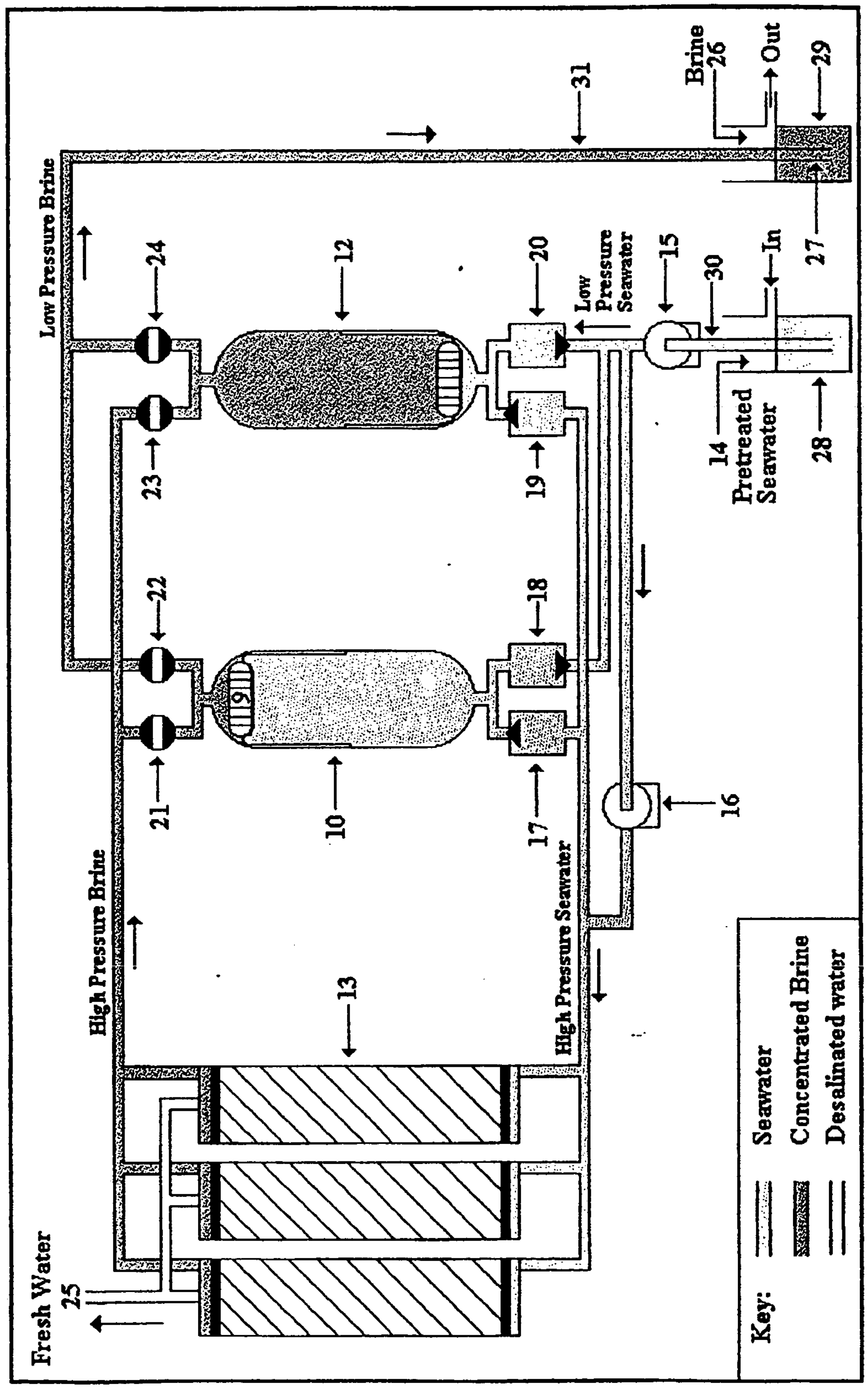


Figure 4a

Figure 4b

Figure 5


Fresh Water
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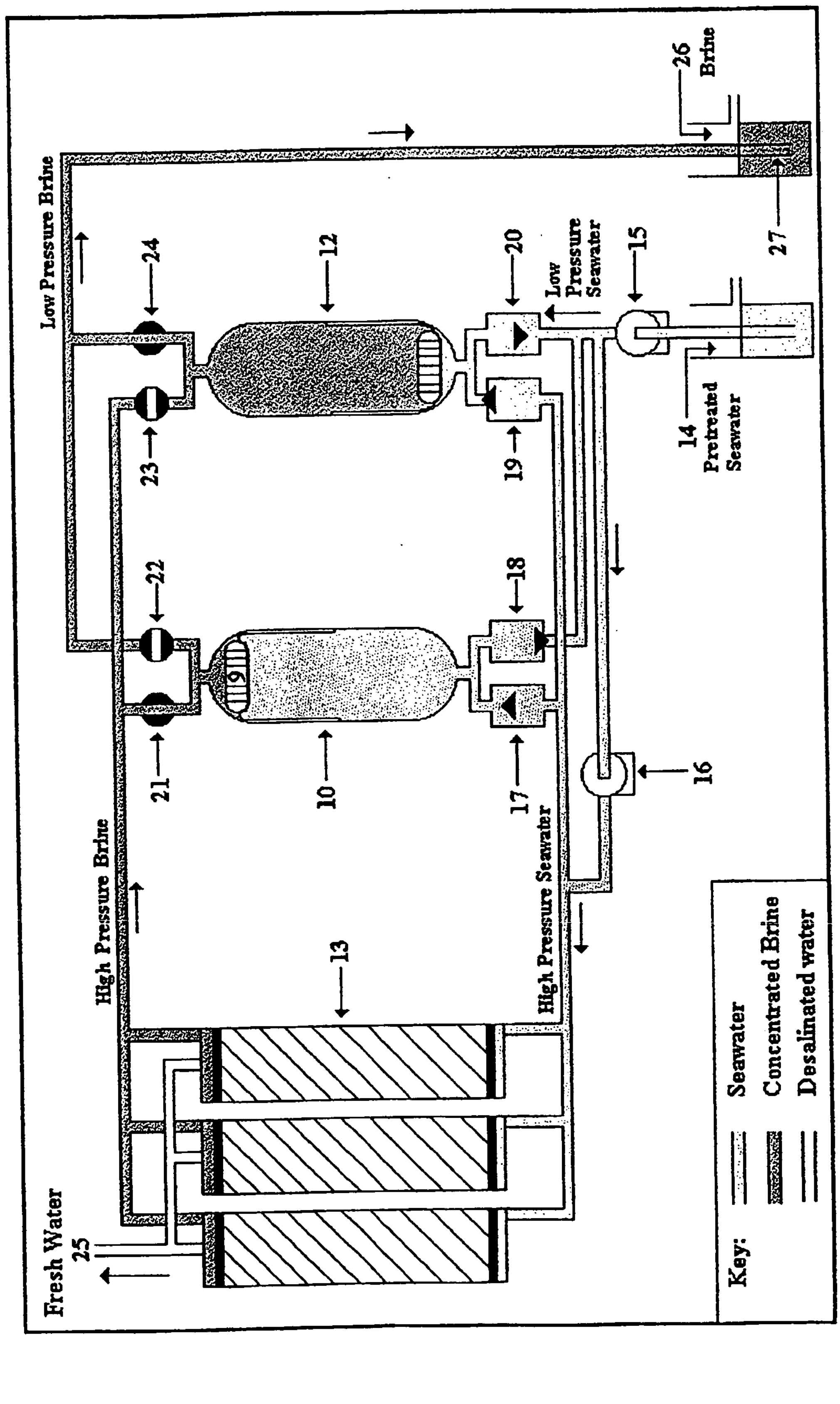
Key:
Seawater
Concentrated Brine
Desalinated water

Figure 6



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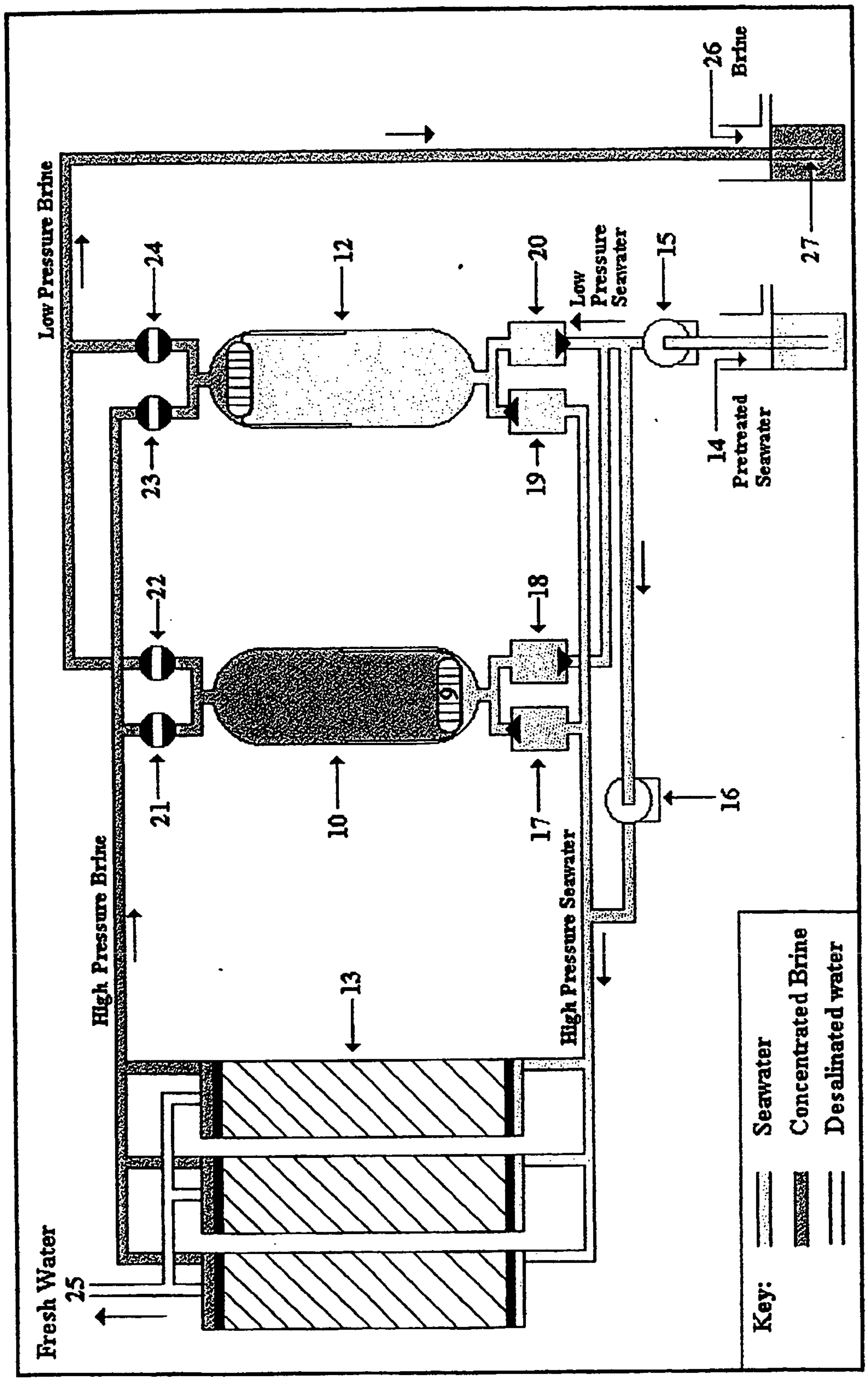
Seawater
Concentrated Brine
Desalinated water

Figure 7



Low Pressure Brine
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Low Pressure Seawater
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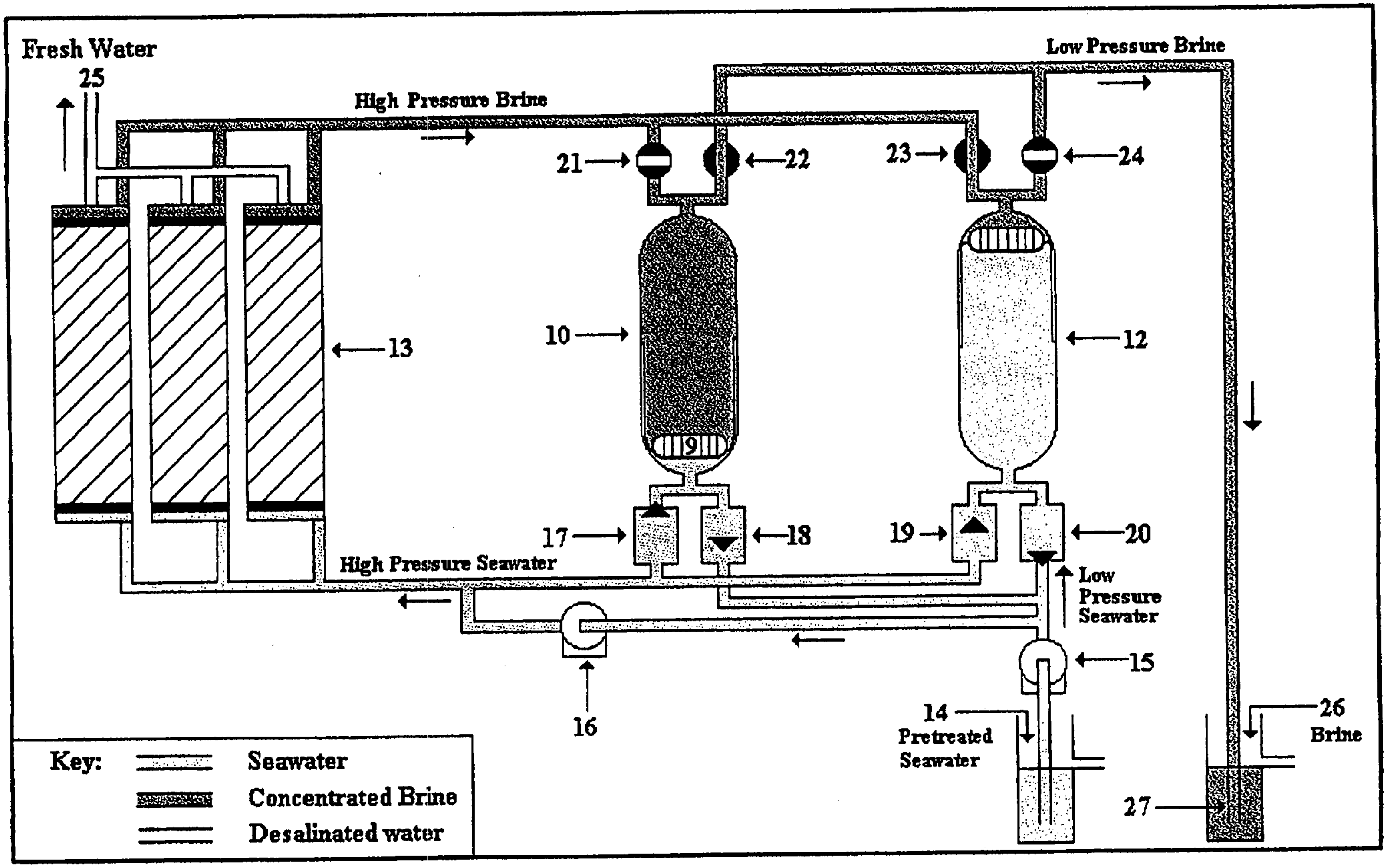
Desalinated water

Figure 8


Fresh Water
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Desalinated water

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Energy Recovery System

The present invention relates to a water desalination system, a method for recovering the energy used in reverse osmosis desalination processes, and a method for the desalination of seawater.

In arid countries and islands, the desalination of sea water is an important means of producing potable water. A number of techniques are available to produce fresh water from seawater, including various processes that use evaporation and distillation techniques. An alternative to the use of evaporation methods is to use a reverse osmosis system that utilises polymer separation membranes to produce desalinated water.

A major limitation of all desalination systems is the high cost of the energy that is required to produce fresh potable water from seawater. With regard to reverse osmosis systems, the seawater has to be supplied to the separation module under a constant, high, pressure in order for the system to work effectively, and the need to use high pressure pumps is a major contributor towards high electrical energy costs.

The well known technology of a reverse osmosis desalination system is simply illustrated in Figure 1, from which it can be seen that the seawater feed is pumped under high pressure into the membrane separation module. High pressure is required to ensure effective separation in the reverse osmosis module and to provide an adequate seawater flow through the system.

On leaving the membrane module, the retentate brine is still at high pressure, albeit at a lower level than the original in-feed pressure. In the simplified system shown in Figure 1, if the brine was discharged straight back into the sea, the energy in the retentate brine, in the form of pressure in the retentate stream, would be

lost, resulting in an inefficient process with high energy costs.

It is acknowledged that the reverse osmosis process can be made more efficient by making use of the pressure available in the retentate brine as it leaves the membrane separation module. Utilising this pressure to perform work in the reverse osmosis process can provide a significant degree of energy recovery and lead to reduced electrical energy costs.

Various methods of energy recovery have been applied to reverse osmosis systems, including turbines, Pelton wheels, reverse running pumps and reciprocating pistons. The use of these energy recovery techniques has resulted in a gradual decline over recent years in the electrical energy needed to operate reverse osmosis processes, from a level of over 10 kWh/cubic metre of water, down to about 2.6 kWh/cubic metre when using the latest reciprocating piston systems. The electrical requirement quoted here is for the reverse osmosis process only and does not include the energy needed for either the pre-treatment of the seawater (extraction from the sea, filtration, chemical treatment) or the post-treatment (storage, distribution) of the desalinated potable water.

One of the most common methods of recovering energy in a desalination system is the use of a reciprocating piston. One such system is illustrated in Figure 2. [This principle is also shown in Figure 3 of "Desalination & Water Re-use" Vol 8/4, p27-33 (Shamway).]. However, as shown in Figure 2 when reciprocating pistons are used as a method of energy recovery, a boost pump is installed immediately after the piston arrangement, i.e. in the line leading from the "piston" and joining the main feed line providing seawater into the water desalination modules. This "boost" pump is needed in order to raise the pressure of the seawater leaving the pistons. Although using a

boost pump allows the output of the high pressure pump be reduced, it does mean that three pumps are required in the system, i.e. a seawater supply pump, a high pressure pump and a boost pump. The need to use three pumps in the reverse osmosis operation, when using reciprocating pistons to recover the energy from the retentate brine, places extra electrical energy demands on the system. A further disadvantage of energy recovery by means of reciprocating pistons is that some energy is lost in overcoming the friction generated during the action of the pistons. This can result in the seawater leaving the pistons at a lower pressure than is available, in theory, from the retentate brine.

The present invention seeks to provide an energy recovery system that further reduces the electrical energy requirement of reverse osmosis processes by a significant degree.

Viewed from one aspect, the invention provides a water desalination system comprising a reverse osmosis unit and at least one buffer tank, wherein the buffer tank comprises a first compartment for receiving retentate brine from the reverse osmosis unit and a second compartment for receiving seawater, said compartments being separated by a movable wall or barrier, and a load arranged to act on said wall or barrier so as to assist flow of seawater out of said second compartment and into the reverse osmosis unit.

The invention also provides a method for desalination of seawater comprising:

- alternate filling and emptying of a buffer tank with seawater;
- feeding seawater from said buffer tank to a reverse osmosis unit;
- desalinating of said seawater in said reverse osmosis unit to produce a fresh water product stream and a high pressure brine reject stream,
- feeding said high pressure brine to said

buffer tank to assist in expulsion of seawater from said buffer tank; and

- applying a load to said seawater to further assist its expulsion from said buffer tank.

In yet a further aspect the invention provides a method of recovering energy from a reverse osmosis desalination system, wherein the high pressure retentate brine coming from the reverse osmosis module is introduced into the top of a buffer tank containing seawater and the retentate brine is used to displace the seawater, under pressure, from the bottom of the buffer tank into the seawater in-feed line leading to the reverse osmosis module, the brine and seawater layers being separated by an impermeable barrier inside the tank, and increasing the pressure of the seawater leaving the tank by applying an additional load to the seawater within the buffer tank.

The invention works on the general principle that the energy contained in the retentate brine coming from a reverse osmosis desalinisation module can be recovered by using the pressure of the brine stream to displace seawater, which is contained in a buffer storage tank (preferably standing in an upright position), from the tank into the in-feed seawater stream that leads to the reverse osmosis separation module. The pressure of the seawater as it leaves the buffer tank is further boosted above the pressure level that is available from the retentate brine alone, by applying an additional load to the seawater inside the tank. The load could, for example, be applied by resilient means for example a spring or a stretchable membrane or other flexible means which have been pre-loaded (e.g. put under tension or compression) during discharge of brine from the buffer tank, preferably, however, the load is applied by a weight acting on the seawater.

The load may take any convenient form, but preferably it is in the form of a disc preferably of

metal, which is positioned inside the tank in such a way that the disc sits on top of the wall or barrier separating the retentate brine from the seawater. Preferably, the disc has rounded sides and the external diameter of the disc is less than the internal diameter of the cylindrical walls of the buffer tank.

Thus, energy in the form of the pressure in the retentate brine is converted into useful work in the reverse osmosis system. Unlike energy recovery systems that use reciprocating pistons, in the method of the invention only a single high pressure pump, operating at a much lower pressure level than normal, is required to feed the seawater to the reverse osmosis module at the required pressure and flow rate. As mentioned above, the single high pressure pump can operate without the need for a boost pump because the seawater pressure is already boosted by the load acting on the seawater within the buffer tank.

It will be appreciated that the movable barrier in the buffer tank allows the volume of the first and second compartments to vary during the filling and discharge cycles while the total volume of the tank remains constant. The barrier is able to move freely within the buffer tank.

In a preferred embodiment of the invention, the brine and seawater in the buffer tank are separated from each other and prevented from mixing during the filling and discharge operations by means of the barrier in the form of a flexible, impermeable liner, e.g. a polymer liner. The liner is conveniently anchored inside the buffer tank, at a predetermined point around the inner circumference of the tank, and the liner is shaped and sized so that it is able to freely move up and down within the buffer tank, depending on the filling and discharge cycle. The predetermined point may for example be a position approximately half way up the tank e.g. approximately in the middle with respect to the

vertical height of the tank. As well as providing a barrier between the brine and seawater in the tank, the liner can also serve to support the weight as it travels up and down the tank, with the aid of the seawater and brine on either side of the liner.

This arrangement is advantageous in that it minimises frictional losses within the system so from a further aspect, the invention provides a seawater desalination system comprising a desalination unit and a buffer tank having a flexible impermeable diaphragm separating the tank into respective compartments for receiving seawater and retentate brine.

The buffer tank is preferably in the form of a metal pressure vessel, which has a filling and discharge tube located at each end thereof. In order to take advantage of the pressure head of the liquid in the buffer tank(s), it is desirable to stand the tank in an upright position in order to maximise the pressure heads. Preferably the buffer tank is circular in cross-section e.g. the buffer tank may be substantially cylindrical.

The volume of the buffer tank would typically be between 50 and 200 litres, e.g. 100-150 litres depending on the capacity requirements of the system. The size of the load within the buffer tank would again be dependent on the capacity requirements of the system and would typically be between 10 and 100 kg, preferably 20 to 50 kg.

The use of a weight within the buffer tank ensures that when seawater is discharged from the tank into the seawater in-feed line leading to the separation modules, it does so under a boosted high pressure. Although some work is required to raise the weight back up the buffer tank this can be offset by a syphon action. Preferably, therefore, the system is arranged such that a syphon effect is produced at the top of the buffer tank. This may be achieved by ensuring that the reject brine pipe

leading from the buffer tank is not open to the atmosphere. Hence, the open bottom end of the pipe preferably discharges under a liquid surface.

Introducing a gravity syphon from the top of the tank to a point below the top of the tank forms a vacuum at the top of the tank. The resulting pressure drop is equivalent to exerting an upward pressure on the load inside the tank. As well as providing a pressure drop to help raise the load, the syphon action can also help to reduce the operating pressure of the seawater supply pump.

The pressure drop at the top of the tank during the brine discharge operation, makes it relatively straightforward to calculate the optimum size of the load that could be used inside the tank, whilst ensuring that virtually no extra energy is required to raise the load back up the tank. For example if the brine reservoir (or more specifically the open end of the brine reject pipe) is situated 9.8m below the level of the top of the buffer tank, there is a pressure drop (or vacuum) of 1 atmosphere between these points and this is equivalent to exerting an upwards pressure of almost 15 psi on the load inside the tank.

The use of a syphon to assist in filling a buffer tank with seawater in a water desalination system is novel in its own right, so from a further aspect, the invention provides a seawater desalination system comprising a desalination unit and a buffer tank having a movable wall or barrier separating the tank into respective compartments for receiving seawater and retentate brine, wherein means is provided to provide a syphon effect at the exit of the brine compartment to assist in displacement of brine from that compartment. In effect, the syphon action has a threefold effect i.e. it causes the brine to be displaced from the buffer tank, and at the same time, helps to raise the load in the tank and assists in drawing seawater into the lower

compartment of the tank.

The number of tanks used in the energy recovery system would be dependent on the volume of seawater to be desalinated by the reverse osmosis membrane modules.

It is preferred that the water desalination system comprise a multiplicity of energy recovery buffer tanks, each of which may be at a different stage of operation in the brine and seawater filling and discharge cycles, to ensure that the seawater flow from the buffer tank arrangement will at a constant flow rate and pressure when it joins the seawater in-feed stream leading to the reverse osmosis separation modules.

In the method of the invention, the volume and flow rate of the seawater displaced from the buffer tanks is equivalent to that of the retentate brine coming from the membrane modules, although the seawater is at a boosted pressure because of the load applied to the seawater within the tanks. The high pressure pump in the system therefore only has to supply a volume of seawater, at the required flow rate and pressure, equivalent to the permeate flow of freshwater exiting the reverse osmosis modules.

This allows the output of the high pressure pump in the in-feed seawater line to be reduced significantly, from e.g. a typical pressure of 60 to 70 atmospheres in traditional reverse osmosis desalination systems, down to a pressure of e.g. 20 to 30 atmospheres when using the method of energy recovery described.

The efficiency of the proposed method of energy recovery contrasts with, for example, the use of energy recovery by means of reciprocating pistons, where some energy is lost in overcoming the friction generated during the action of the pistons.

Thus, the reverse osmosis desalination system of the invention works by applying a load to the seawater within a buffer tank, in addition to the high pressure available in the brine retentate stream, so that the

seawater is discharged from the tank under a boosted high pressure. The advantage of this is that the reverse osmosis system is able to operate by means of a high pressure pump, operating at a much lower pressure than normal, and a low pressure seawater supply pump only, i.e. unlike some known systems, where an additional "boost pump" is required in their system.

The electrical energy required to run the reverse osmosis operation is therefore significantly reduced, when compared with systems that use alternative methods of energy recovery.

The method of the invention will now be described with reference to preferred embodiments shown in the schematic illustrations given in Figures 1 to 8 inclusive, where:

Figure 1 illustrates the general principle of a reverse osmosis desalination system;

Figure 2 shows a prior art desalination plant using a reciprocating piston arrangement to recover energy from retentate brine;

Figures 3a and 3b show a pressure resistant buffer tank in accordance with the invention in vertical section;

Figures 4a and 4b show an alternative design of pressure resistant buffer tank; and

Figures 5, 6, 7 and 8 show a desalination system in accordance with the invention at different stages during its operation cycle.

With reference to Figures 3 to 8, an embodiment of the invention and certain of its component parts are shown.

As shown in Figure 5, the system broadly comprises a bank of reverse osmosis units 13 which receive seawater from a reservoir 28. Seawater is fed to the units 13 from a reservoir 28 via a low pressure supply pump 15 and a high pressure pump 16. A proportion of the seawater at low pressure is fed from the low

pressure pump 15 to the desalination units 13 via a pair of buffer tanks 10, 12, as will be described further below.

After passage through the reverse osmosis units 13, high pressure retentate brine leaving the reverse osmosis units 13 is fed to a reservoir 29 via the buffer tanks 10, 12 so as to recover some of the energy in the retentate brine. The flow of seawater and retentate brine into and out of the buffer tanks is controlled by respective valves 17-24.

Operation of the system will be described further below.

As will be clear from what follows, the buffer tanks 10, 12 form an important part of the invention. Their construction will now be described in more detail with reference to Figures 3 and 4.

In the buffer tank design illustrated in Figure 3a, the tank is constructed from two identical metal cylinders, 1 and 2, said cylinders being hemi-spherical at one end and open at the other end. At the apex of the hemi-spherical end of each cylinder there is a discharge/inlet tube 3. At the open end of each cylinder there is an outwardly extending flange 4 which extends completely around the circumference of the open end of the cylinder, said flange 4 being at right angles to the walls of the cylinder. The flange 4 on each cylinder has holes 5 there through, said holes 5 being positioned at regular, fixed intervals around the circumference of the flange 4 and in corresponding positions on each cylinder flange 4. This allows the two cylinders 1 and 2 to be joined together, by aligning the holes 5 on the top and bottom flanges 4 and using nuts and bolts 11, or other suitable fastenings, located through holes 5 for fixing the cylinders together.

A compressible pressure seal 6 is provided on the outer side of each flange 4, i.e. the side of the flange 4 which abuts with the flange 4 opposite when the two

cylinders are joined together. The pressure seals 6 also include holes that correspond in position to the holes 5 in the flanges 4 to allow the insertion of fastenings 11 (Figure 3b) when the two cylinders are joined together.

A flexible, impermeable polymer liner 7, shaped to fit the internal contours of either cylinder 1 or cylinder 2, is shown located in the bottom cylinder 2 so that the edge 8 of the liner 7 overlaps the compressible pressure seal 6 located in the external flange 4 of the bottom cylinder 2. The liner 7 is shaped and sized so as to be able to lie flush with and to completely cover the internal surface of the cylinder 2.

A load, in the form of a smooth weighted metal disc 9, is located at the base of the bottom cylinder 2 on top of the polymer liner 7. The disc 9 has rounded sides and the external diameter of the disc is smaller than the internal diameter of cylinders 1 and 2, so that the disc 9 can freely move up and down the cylinders without generating friction between the edges of the disc and the internal side walls of the cylinders.

Electronically operated valves 17 and 18 are located at the exit of tube 3 positioned at the top of cylinder 1. Unidirectional pressure activated valves 21 and 22 are located at the exit of tube 3 positioned at the base of cylinder 2.

Figure 3b shows the buffer tank 10 of Figure 3a as assembled. The abutting pressure seals 6 in the top and bottom flanges 4 are fully compressed so that the cylindrical tank 10 is pressure resistant.

The edge 8 of the flexible liner 7 is sandwiched between the upper and lower pressure seals 6, and the pressure seals 6, when in the compressed state, hold the edge 8 of the liner 7 tightly in position.

Figure 3b also illustrates how the flexible liner 7 is free to move between the base cylinder 2 and the top cylinder 1 of the buffer tank 10 depending on the

filling/discharge cycle of the energy recovery process. As the liner moves from the bottom of cylinder 2 to the top of cylinder 1, through the pressure generated by seawater entering the buffer tank 10 underneath the liner 7, the metal disc 9 is pushed up by the liner 7 to the top of tank 10 as shown in Figure 3b.

The electronically controlled valves 17 and 18, located at the exit of tube 3, at the top of tank 10, allow the filling and discharge of retentate brine in and out of the buffer tank 10, whilst the unidirectional pressure activated valves 21 and 22, located at the exit of tube 3 at the bottom of tank 10, control the filling and discharge of seawater in and out of buffer tank 10.

The flexible liner 7 acts as a separating, impermeable barrier between the layers of retentate brine and seawater within tank 10 when the pressure vessel is being filled and emptied alternately with brine and seawater. Liner 7 also separates the load, that is the weighted disc 9, from the seawater layer in tank 10.

The operating sequences of the valves 17, 18, 21 and 22, which are located at the top and bottom exit points 3 of the buffer tank 10, in relation to the filling and discharge cycles of seawater and brine into and out of the buffer tank, will be explained more fully below with reference to Figures 5, 6, 7 and 8.

The buffer tank described in Figures 3a and 3b illustrates one possible design of tank. To those skilled in the art, it would be obvious that other similar tank constructions could be used.

For example, an alternative design of buffer tank is illustrated schematically in cross-section view in Figures 4a and 4b. Although similar to the tank illustrated in Figures 3a and 3b, in Figures 4a and 4b the tank consists of a metal cylinder 2', open at one end, with other end being hemi-spherical in shape and including a filling/discharge tube 3' at the apex of the

hemi-sphere, said tube being connected to a valve arrangement 21', 22'. At the open end, the cylinder 2' has an outwardly extending flange 4' for connection to the top of the tank, which is constructed from a metal plate 1' with a filling/discharge tube and a valve arrangement 17', 18' located in the centre of the plate. The plate includes holes 5' around the periphery of the plate, corresponding in position to holes 5' in the external flange 4' on the cylinder 2', to allow the end plate 1' to be joined to the cylinder 2' by means of nuts and bolts 11'.

In the design illustrated in Figures 4a and 4b, the flexible liner 7' is anchored inside the buffer tank by means of the flanged joint located at the top of the tank, rather than centrally within the tank as shown in Figures 3a and 3b. The liner 7' is again sized and shaped so as to be able to completely cover the inside surface of the tank, and be able to move up and down the tank during the seawater and the brine filling operations.

In a further similar alternative design, the buffer tank could be constructed from a metal tube with metal plates affixed to each end of the tube.

The overall system of the invention and its mode of operation will now be more fully described with reference to Figures 5, 6, 7 and 8.

Figure 5 shows two cylindrical buffer tanks, 10 and 12, standing in an upright, vertical position, at the moment in the energy recovery cycle when tank 10 has been filled with seawater through valve 18 by the seawater supply pump 15, and tank 12 has been filled with retentate brine through valve 23, the brine having come, under pressure, from the reverse osmosis separation modules 13. The weighted metal disc 9 is at the top of tank 10 lying on top of the seawater layer, supported by the polymer liner 7, whilst the disc in tank 12 is at the bottom of the tank.

Pre-treated seawater 14 is pumped from either a storage well or reservoir 28 by a supply pump 15 through pipe 30. Reject brine 26 from the energy recovery system is discharged through pipe 31 to a storage well or reservoir 29. The seawater supply pipe 30 and the brine discharge pipe 31 are arranged so as to provide a syphon effect between the brine discharge and the seawater in-feed.

The syphon action produces a reduction in pressure at the top of the buffer tank, which assists in filling the buffer tank with seawater and helps to raise the disc 9 back up the tank during the seawater filling cycle, thus reducing the work required to lift the weight in the tank. To maintain the syphon effect, the lower end 27 of the brine discharge pipe is maintained submerged in the reservoir 29.

A high pressure pump 16 pumps seawater, from the supply line leaving pump 15, to the reverse osmosis separation modules 13 at the required pressure and flow rate to provide optimum desalination.

In Figure 5 only a small number of separation modules are illustrated. In practice there may be a multiplicity of reverse osmosis modules to provide the desired volume of desalinated water. Standard designs of reverse osmosis modules can be used in the desalination process, of either the spirally wound or hollow fibre membrane separation type.

The supply pump 15 diverts some seawater under low pressure into an in-feed line for the replenishment of the buffer tanks 10 and 12 with seawater as appropriate. This low pressure line is kept separate from the high pressure seawater feed line leading to the separation modules that is generated by the high pressure pump 16.

Permeate fresh water 25 exits the separation modules 13 under low pressure to be stored in storage tanks (not shown). Retentate brine exits the reverse osmosis modules 13 under high pressure and the high

pressure retentate brine line that leads to the buffer tanks is kept separate from the low pressure reject brine line that discharges brine from the buffer tanks to the brine reservoir.

At this point in the energy recovery cycle, the seawater pressure activated valves 17, 18, 19 and 20 at the base of buffer tanks 10 and 12 are closed, as are the electronically controlled brine valves 21, 22, 23 and 24 at the top of the tanks.

The next stage of the energy recovery operation is illustrated in Figure 6.

The electronically controlled brine valve 21 in buffer tank 10 opens. Because of the high pressure of the brine entering through valve 21 from the separation modules, combined with the load of the weighted disc 9, the seawater pressure valve 17 opens and allows seawater, at a boosted pressure, to enter the high pressure seawater line leading to the separation modules. Brine valve 22 in tank 10 is closed to prevent the high pressure brine within tank 10 entering the low pressure brine discharge line. The high pressure that has been generated in tank 10 ensures that the pressure valve 18, which leads to the low pressure seawater in-feed line from the supply pump 15, remains closed.

At the same time as valve 21 opens in tank 10, the electronically controlled valve 24 opens in tank 12. Because of the syphon effect between the brine discharge and the seawater supply pipes, there is a pressure drop between the brine in tank 12 and the reject brine in the discharge line. This pressure drop, combined with the pressure of the seawater supplied by pump 15, opens pressure valve 20. The combination of the syphon effect and seawater pressure is sufficient to push seawater into tank 12 through valve 20, raise the weighted disc in tank 12 back up the tank and displace the reject brine from the top of the tank through valve 24. Brine valve 23 in tank 12 is closed to prevent high pressure

brine from the separation modules 13 entering the low pressure brine discharge line. High pressure in the in-feed seawater line leading to the separation modules ensures that pressure valve 19 in tank 12 remains closed and prevents high pressure seawater entering tank 12.

The brine and seawater filling and discharge operations continue in both tanks until tank 10 is filled with brine and tank 12 with seawater. The brine and the seawater layers in tanks 10 and 12 are separated and prevented from mixing by the flexible, impermeable liners 7 inside the tanks (shown in Figures 3a, 3b, 4a and 4b). The liners in tanks 10 and 12 also separate the weighted discs from the seawater layers within the tanks and ensure that the discs can move down and up tanks 10 and 12 respectively during the filling and discharge operations.

Figure 7 shows the stage in the energy recovery cycle when tank 10 is full with brine and tank 12 with seawater. The weighted disc 9 in tank 10 is at the bottom of the tank and the disc in tank 12 is at the top of the tank. At this point, the electronic brine valves 21 and 24 close. Seawater pressure valve 20 closes because of the pressure resistance built up in tank 12. Seawater pressure valve 17 closes because of the back pressure in the high pressure in-feed line. At this stage in the energy recovery cycle, all the brine and seawater valves to tanks 10 and 12 are closed.

Figure 8 illustrates the next stage of the energy recovery cycle. Electronic valve 23 in the high pressure brine line leading into tank 12 opens and the high pressure of the retentate brine entering tank 12, plus the load of the weighted disc in tank 12, opens the seawater pressure valve 19 and seawater is displaced from the tank into the high pressure seawater in-feed line leading to the separation modules. The combination of brine pressure and load ensures that the seawater leaving tank 12 is under boosted pressure when it enters

the high pressure line leading to the separation modules.

Electronic valve 24 in the low pressure brine line leading from tank 12 remains closed to prevent the high pressure brine within tank 12 entering the low pressure brine discharge line. The high pressure in tank 12 ensures that the seawater pressure valve 20 remains closed, thus preventing the entry of new seawater into tank 12 during the brine filling operation.

Meanwhile in tank 10 electronic valve 22 opens, at the same time as valve 23 in tank 12. The drop in pressure between tank 10 and the brine discharge line, due to the syphon action, combined with the pressure of the seawater supply from pump 15 to tank 10, opens pressure valve 18. The combination of the syphon effect and the seawater supply pressure fills tank 10 with new seawater through valve 18, whilst discharging brine through valve 22, and simultaneously raises the disc 9 in tank 10. Brine valve 21 in tank 10 is closed to prevent the flow of high pressure brine into the low pressure discharge line. Seawater pressure valve 17 is closed by the high back pressure in the in-feed line leading to the separation modules.

The flexible impermeable liners in tanks 10 and 12 again separate the brine from the seawater in each tank, as well as separating the weighted discs from the seawater layers and supporting the discs as they move up and down tanks 10 and 12 respectively.

Once tank 10 has filled with seawater and the weighted disc 9 is at the top of the tank, and tank 12 has filled with brine and the weighted disc is at the bottom of the tank, all valves in both tanks close and the system has returned to the state illustrated in Figure 4. The energy recovery cycle is then ready to be repeated.

In Figures 5 to 8, in order to simplify the description of the energy recovery method, the operation

of only two buffer tanks is illustrated. In practice there may be a multiplicity of buffer tanks, each at a different stage of operation, so that a constant flow of seawater is being provided from the tanks to the seawater in-feed line leading to the reverse osmosis modules.

The efficiency of the energy recovery method and its effect on reducing electricity demand is illustrated more fully in Tables 1 and 2, which summarise the working pressures and electrical energy requirements of a reverse osmosis desalination system that utilises the energy recovery method described in the invention. The data given in Tables 1 and 2 is based on measurements taken from an experimental test rig that incorporated the energy recovery method of the invention.

Table 1 provides a breakdown of the working pressures and electrical energy demands of a reverse osmosis system that incorporates the proposed energy recovery method, to desalinate seawater with a salt concentration of 3.5%, a typical salinity level for normal seawater.

Table 2 gives the total working pressures and electrical energy demands that are required to desalinate water containing differing concentrations of salt.

The electrical energy demands shown in Tables 1 and 2 are for the reverse osmosis system only and do not include either the energy required for the pre- and post-treatment of the water or the very small amount of electricity required to operate the electronic valves in the system.

Table 1

Breakdown of working pressures and electrical energy demands for normal seawater

Measurement	Value
Water salinity, % mass	3.5
Salt water flux by delivery pump, gpm	0.158
Supply pump pressure, psi	2.9
Supply pump efficiency, %	70
Supply pump energy requirement, kW	0.000571
Water flux through high-pressure pump, gpm	0.0166
High-pressure pump pressure, psi	503
High-pressure pump efficiency, %	70
High-pressure pump energy requirement, kW	0.00479
Total energy requirement for pumps, kW	0.00536
Desalinated water flux, gpm	0.0166
Total energy demand, kWh/cubic metre	**1.5**

Table 2

Total working pressures and electrical energy demands for seawater with differing salt concentrations

Water Salinity %	**Working Pressure** Psi	**Energy Requirement** kWh/cubic metre
1.8	280	0.9
2.7	430	1.3
3.5	500	1.5
4.1	570	1.8

Table 1 shows that by using the proposed energy recovery method, the electrical energy required in the reverse osmosis system is 1.5 kWh/cubic metre of water, when using normal seawater with a salinity of 3.5%. This is almost half the electricity demand of reverse osmosis systems that use reciprocating pistons as a means of energy recovery, when the two systems are compared on the same basis, i.e. excluding the pre- and post-treatment of water and the electricity required to operate valves.

In addition to seawater, the energy recovery method of the invention could also be used with reverse osmosis

systems that are used to obtain fresh water from brackish water, which usually has lower salt contents. It will be appreciated, therefore, that the term "seawater" as used herein is also meant to encompass any form of liquid with a high ion (salt) concentration which can be purified by means of reverse osmosis to recover a desired product having a lower ion (salt) concentration.

Claims

1. A water desalination system comprising a reverse osmosis unit and at least one buffer tank, wherein the buffer tank comprises a first compartment for receiving retentate brine from the reverse osmosis unit and a second compartment for receiving seawater, said compartments being separated by a movable barrier, and a load arranged to act on said barrier so as to assist flow of seawater out of said second compartment and into the reverse osmosis unit.

2. Water desalination system as claimed in claim 1 wherein said load is attached to or positioned above said movable barrier whereby to separate said load from the seawater in said second compartment.

3. Water desalination system as claimed in claim 1 or 2 wherein said load is a metal disc.

4. Water desalination system as claimed in any preceding claim wherein said buffer tank is in an upright position.

5. Water desalination system as claimed in any preceding claim comprising at least two buffer tanks.

6. Water desalination system as claimed in any preceding claim wherein the buffer tank is a metal pressure vessel, which has a filling and discharge tube located at each end of the buffer tank.

7. Water desalination system as claimed in claim 6 wherein the filling and discharge tube at the top of the buffer tank is connected to electronically controlled valves that regulate the filling and discharge of brine in and out of the buffer tank.

8. Water desalination system as claimed in claim 6 wherein the filling and discharge tube at the bottom of the buffer tank is connected to unidirectional pressure activated valves that regulate the filling and discharge of seawater in and out of the buffer tank.

9. Water desalination system as claimed in any preceding claim wherein said movable barrier is a flexible impermeable liner.

10. Water desalination system as claimed in claim 9 wherein said liner is anchored at a predetermined point around the inside circumference of the cylindrical walls of the buffer tank, and the liner is so shaped and sized as to allow it to freely move up and down within the tank.

11. Water desalination system as claimed in any preceding claim comprising means for feeding the seawater from a seawater reservoir to the buffer tank and means for carrying reject brine from the buffer tank to a brine reservoir, and wherein the reservoirs and the means for feeding the seawater from the seawater reservoir and for carrying the reject brine to the brine reservoir are so arranged as to provide a syphon action, assisting expulsion of reject brine from the buffer tank and causing the load to rise within the tank.

12. Water desalination system as claimed in any preceding claim wherein the system comprises a plurality of reverse osmosis units.

13. A method for desalination of seawater comprising:

- alternate filling and emptying of a buffer tank with seawater;
- feeding seawater from said buffer tank to a reverse osmosis unit;

- desalinating of said seawater in said reverse osmosis unit to produce a fresh water product stream and a high pressure brine reject stream,
- feeding said high pressure brine to said buffer tank to assist in expulsion of seawater from said buffer tank; and
- applying a further load to said seawater to further assist its expulsion from said buffer tank.

14. A method of recovering energy from a reverse osmosis desalination system, wherein the high pressure retentate brine coming from the reverse osmosis module is introduced into the top of a buffer tank containing seawater and the retentate brine is used to displace the seawater, under pressure, from the bottom of the buffer tank into the seawater in-feed line leading to the reverse osmosis module, the brine and seawater layers being separated by an impermeable barrier inside the tank, and increasing the pressure of the seawater leaving the tank by applying an additional load to the seawater within the buffer tank.

15. A method as claimed in claim 13 or 14, wherein after the seawater has been emptied from the buffer tank, the tank is recharged with new seawater under low pressure, so displacing the brine in the tank out of the top of the tank into a reject brine discharge pipe, which is at a lower pressure than the seawater that is entering the tank, and where the seawater filling the tank raises the load back up the tank.

16. A method as claimed in any one of claims 13 to 15, wherein there are a multiplicity of buffer tanks each at a different stage of operation in the energy recovery filling and discharge cycles so that the seawater displaced from the buffer tanks into the seawater in-feed line leading to the reverse osmosis module is at a

constant flow rate and pressure.

17. A method as claimed in any one of claims 13 to 16, wherein only two pumps are required, (i) a low pressure supply pump is used to supply seawater at low pressure to the buffer tank, and (ii) a high pressure pump, operating at a lower pressure than is normal in traditional reverse osmosis systems in order to feed seawater from the supply pump to the reverse osmosis module.

19. A method as claimed in any one of claims 13 to 18, wherein a syphon arrangement is provided to assist in expulsion of brine from the buffer tank.

20. A seawater desalination system comprising a buffer tank having a movable barrier separating the tank into respective compartments for receiving seawater and retentate brine, wherein means is provided to provide a syphon effect at the exit of the brine compartment to assist in displacement of brine from that compartment.

21. A seawater desalination system comprising a buffer tank having a flexible impermeable diaphragm separating the tank into respective compartments for receiving seawater and retentate brine.

22. A buffer tank for use in a water desalination system comprising a flexible impermeable diaphragm separating the tank into respective compartments for receiving seawater and retentate brine.

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Application No: GB 0015112.6
Claims searched: 1-20

Examiner: Robert Black
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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): B1X (X6F1, X6A1)

Int Cl (Ed.7): B01D 61/06

Other: Online: EPODOC; WPI; PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2088968 A	(SRI) see especially figures 1 and 2	1, 13 and 14 at least
X	GB 2030056 A	(STEINMULLER) see especially figures 2.1, 2.2 and 7-10	1, 13 and 14 at least
X	GB 1601518 A	(KEEFER) see especially figures 1 and 3-5	1, 13 and 14 at least
X	EP 0055981 A1	(RAMO) see especially figures 2-4	1, 13 and 14 at least
X	US 4929347 A	(IMAI) see especially figures 4 and 5	1, 13 and 14 at least

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